APPENDIX 5

MUSCOY GROUNDWATER MODELING MEMORANDUM
November 1993

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November 9, 1993

Mr. Kevin Mayer (H-6-4)
Work Assignment Manager
U.S. Environmental Protection Agency
Region IX
75 Hawthorne Street
San Francisco, CA 94105

62251.40.41.0061

Subject: Contract No. 68-W9-0054 / WA No. 54-22-9LJ5
Newmark Groundwater Contamination Superfund Site - Muscoy Operable Unit
Task 1.4 Revised Modeling Memorandum

Dear Mr. Mayer:

Attached is a copy of the above referenced revised memorandum. The memorandum summarizes the status of the Muscoy modeling effort and addresses several interesting points. I think this memorandum will serve as a continuing point for further discussions regarding the modeling effort.

If you have any questions or require any additional information, please feel free to contact me at (916) 929-2346.

Sincerely,

URS CONSULTANTS, INC.

Dennis Bane
Site Manager

DB/dlc

Enclosure

(62251-F/mm-musc.r-0)

MUSCOY GROUNDWATER
MODELING MEMORANDUM

NEWMARK GROUNDWATER
CONTAMINATION SUPERFUND SITE

Prepared for:

Contract No. 68-W9-0054 / WA No. 54-22-9LJ5
U.S. Environmental Protection Agency
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1.0 INTRODUCTION

This technical memorandum has been requested by U.S. Environmental Protection Agency (EPA) under subtask 1.4 of the Newmark Groundwater Contamination Superfund Site, Muscoy Operable Unit (Muscoy OU) Statement of Work for Work Assignment No. 54-22-9LJ5.

This memorandum provides an update on the status of the preliminary groundwater modeling effort for the Muscoy OU and will identify model deficiencies and recommend corrective actions. The current model is a refined version of the flow model that was used in the Newmark Remedial Investigation (RI). For a detailed description of the Newmark preliminary model, refer to the document titled *Preliminary Steady-State Model Technical Memorandum* dated October 1991.

The primary objectives of the Muscoy preliminary modeling effort are to identify areas of high uncertainty and critical conceptual or data gaps in the Muscoy OU. The preliminary model is therefore the first stage in achieving the ultimate objective of constructing a model that can be used to assess the feasibility of remedial options. The overall purpose of the model study will be to evaluate the feasibility of a remediation pumping system; and, if this form of remediation is feasible, what pumping scenario should capture the Muscoy contaminant plume.

A preliminary series of model runs was conducted to identify data gaps and to evaluate what impacts that these data gaps may have on the model. Attempts to calibrate the model were conducted through an iterative process. Calibration attempts were partially successful and several recommendations for model improvement are presented. Once satisfactory calibration is achieved, the model will be used to (1) predict whether downgradient water-supply wells may be affected, and (2) assess several potential extraction/remediation scenarios.

2.0 OVERVIEW OF MODEL RUNS

This section is an overview of the model refinement: it presents discussions on the ability of the flow model to define source areas; the model calibration efforts, focusing on the Muscoy OU; evaluations of the model deficiencies; and descriptions of reviews of several variables affecting the model.

Run numbers 42A, 43A, 43B, 44A, 45A, 45B were conducted using imaginary particles to confirm or discount potential point-source locations and geometric changes to the gap area between the Shandin Hills and Wiggins Hill. Run numbers 46 and 47 were reserved for specific analyses but these were not performed. Run numbers 48 and 50 were related to Newmark Operable Unit analyses and will not be discussed here. Runs 49A, 49B, 49C, 49D, 49E, and 51A were all related specifically to refinement of the model calibration. Run series numbers 51, 52, 53, 54, and 55 were conducted to evaluate model responses from pumping at the leading edge of the Muscoy plume. Runs 51B, 51C, and 51D were conducted in order to correlate predicted and observed phenomena from related aquifer pump test data. Runs 52A, 52B, 52C, 53A, and 54A were conducted in order to gain familiarity with extraction scenarios in the Muscoy plume regarding their applicability to the feasibility study. Run 55A includes further model refinements based on understanding gained from runs 49A through 54A. The details of individual runs are described in Appendix A.

2.1 ABILITY OF THE MODEL TO INDICATE POTENTIAL SOURCE AREAS

Analysis of the available groundwater data from existing monitoring wells suggested that groundwater should flow eastward through the gap created by the elevated bedrock of the Shandin and Wiggins Hills. However, at present, the model predicts water flow westward in this area. Resolution of this issue bears directly on the ability of the model to associate a potential source with the Muscoy and/or the Newmark groundwater contaminant plumes. The model may have the analytical power to resolve such issues, given sufficient data.

The model has been used with imaginary particle placement analyses to investigate the suspected source area(s). Success in meeting this goal has been restricted due to the limited resolution of the model in the suspected source area(s) to the north and west of the Shandin Hills. As summarized in Appendix A, model runs 42A, 43A, 43B, 44A, 45A, and 45B were run using various configurations, such as widening the active model area within the gap between Shandin and Wiggins Hills (known as SWG).

The cell size (820 feet x 820 feet) used in the model is an appreciable fraction of the flow paths between the outcropping bedrock in this area. It was therefore possible to increase the available transport area by 33 to 67 percent, depending on the number of cells chosen to represent the width. Model runs 42A, 43A, 43B, 45A, and 45B were set up with various widths.

Despite modeling credible extremes of bedrock topography, the model outputs in the northern area are deficient with regards to assessing source regions. As presently configured, the model shows flow westward through the area between Shandin and Wiggins Hills. Despite reasonable changes in model parameters, the model incorrectly predicts groundwater flow west through the gap. Thus, as the model is currently configured, upgradient sources in the northwestern portion of the model area would incorrectly impact only the Muscoy plume and not both plumes.

Conclusions drawn from a partially calibrated model about specific sources and the impact on a particular plume could be misleading. Subsection 3.2 outlines recommended actions which could increase the utility of the model for this purpose.

2.2 MODEL CALIBRATION

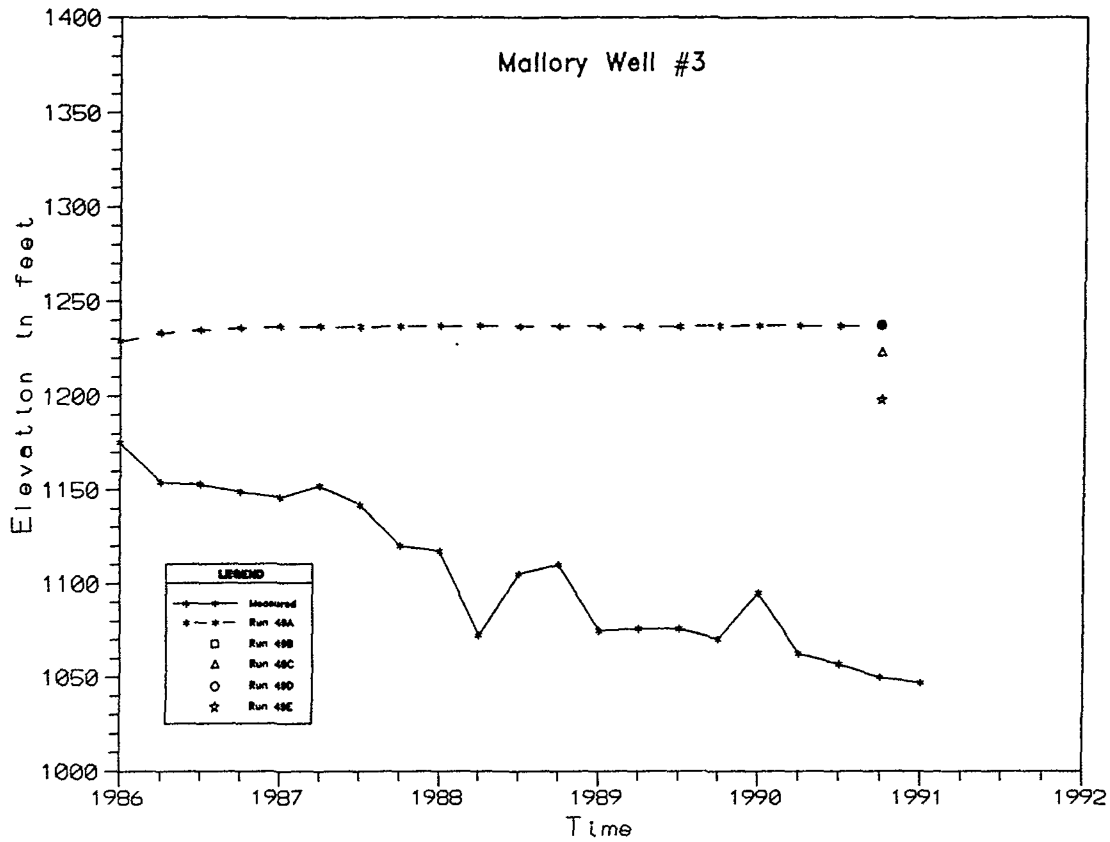
The degree of model calibration achieved is primarily defined by comparison of observed water elevations from wells with those predicted mathematically by the model. Evaluation of model simulations, therefore, has been based primarily on hydrographs from wells for which water level data is available for the simulation time frame. Fluxes, water levels, and anomalies along boundaries, although not highly quantifiable, can also be used as qualitative discriminating criteria to assess if the model is sufficiently calibrated. In addition, other calibration tools included water elevation maps for layers 1 and 2 (the upper and lower alluvial aquifers respectively), cell-by-cell flow files, and water budget summaries generated during each transient-state simulation.

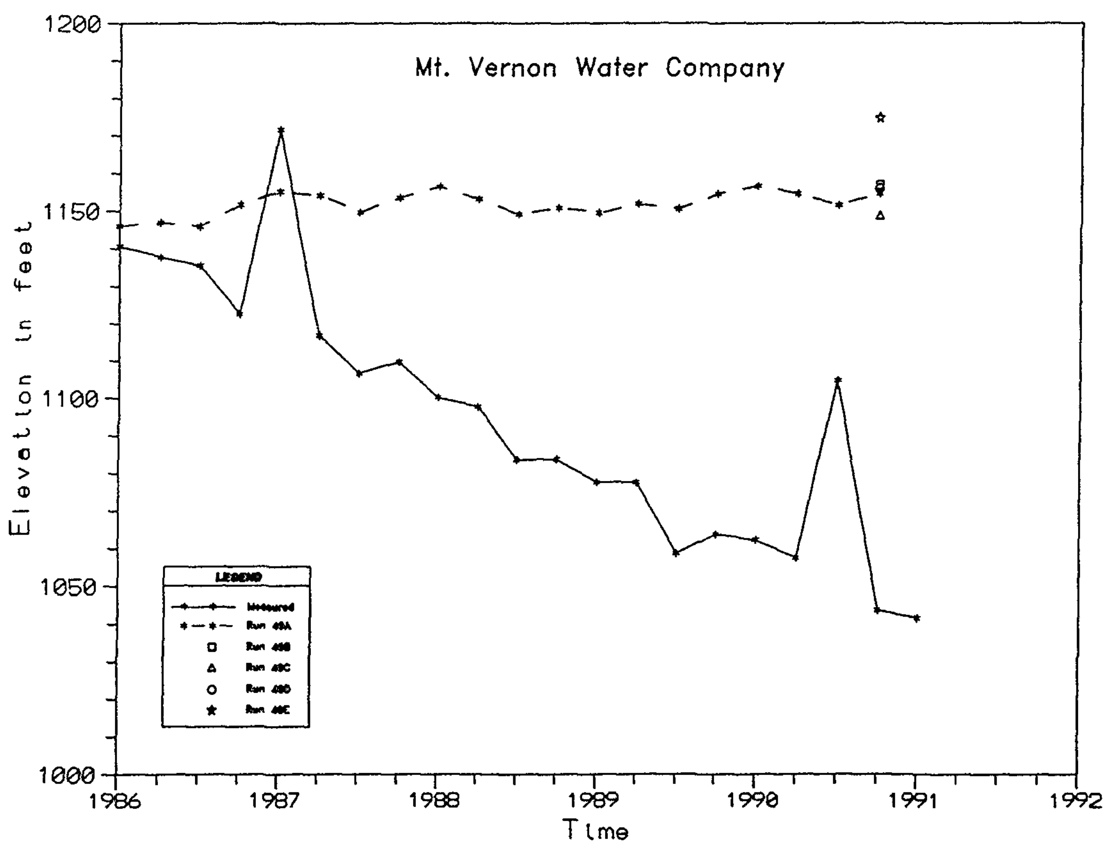
Attempts were made to increase correlation between observed and predicted values by modifying various model parameters, including general head boundary conditions, specific yield, and hydraulic conductivity. Results from some of these runs indicated that refined calibration will require further efforts beyond these modifications (see Subsection 3.1).

The predicted heads generally were higher in the area of the Muscoy plume when compared to observed values. Figures 1 through 9 illustrate observed and predicted water levels for wells in the western part of the model area. Figure 10 shows the locations of these wells. At present, the predicted trends do not follow the observed trends of decreasing head over time, nor do they reflect the observed temporal variations (refer to Figures 1-9). Subsection 3.1 (and Appendix B) identifies potential reasons for this response, along with recommended actions to improve the model's response.

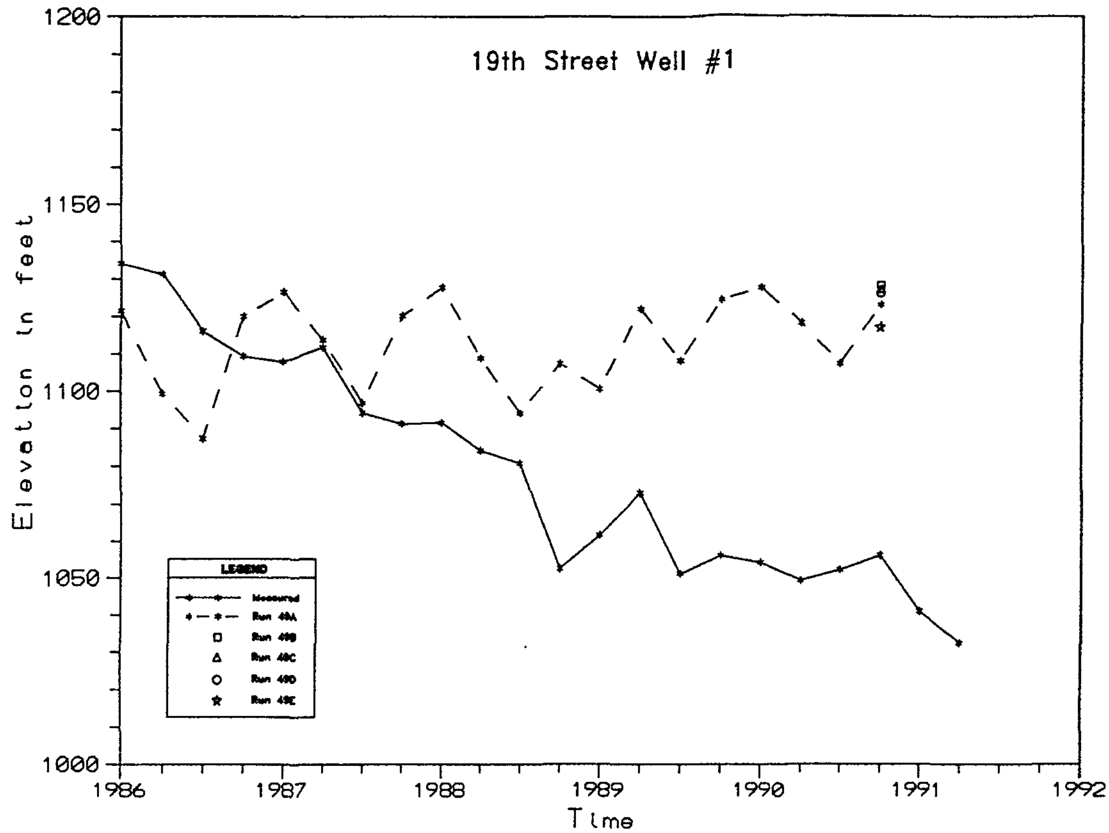
The steady-state calibration head values were used as input for the transient-state and were considered to have good correlation. The perception derived from the steady-state and transient-state simulations performed during the Newmark RI was that the Muscoy area (southwest portion of the model area) was reasonably calibrated. Figure 10 shows the location of the wells that were used to calibrate the model. The predicted values for these wells do not correlate closely with observed values and do not follow the observed trend of decreasing head over time. Predicted head values for the wells in the Newmark plume do not uniformly deviate either high or low compared to observed values. This is unlike the Muscoy plume area where all of the predicted head values are too high.

The overall responsiveness of the model to stresses in the Muscoy plume area is dampened. High frequency input stresses (such as large pumpages of water over a one to two quarter-year interval) were unobserved in the model output (see subsection 3.2, Pumpage Data, for further discussion). This unresponsive characteristic may adversely influence prediction of aquifer behavior during extraction.





URS CONSULTANTS	2710 GATEWAY OAKS DR. SUITE 250 NORTH SACRAMENTO, CA 95834 (916) 929-2346	NEWMARK GROUNDWATER SUPERFUND SITE *MUSCOY OPERABLE UNIT* ARCS, EPA REGIONS IX & X — WA NO. 54-10-9L36	**FIGURE 1** Hydrographs for Mallory Well #3 & Mt Vernon Water Company Wells



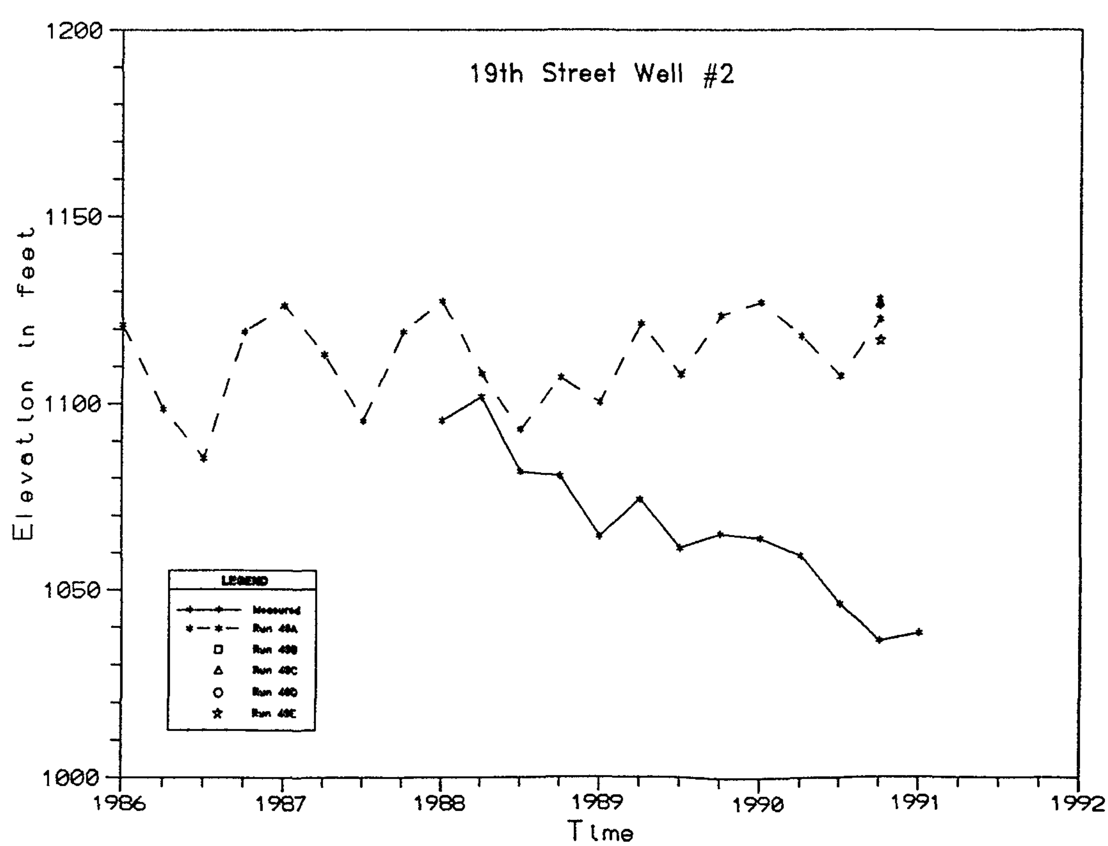


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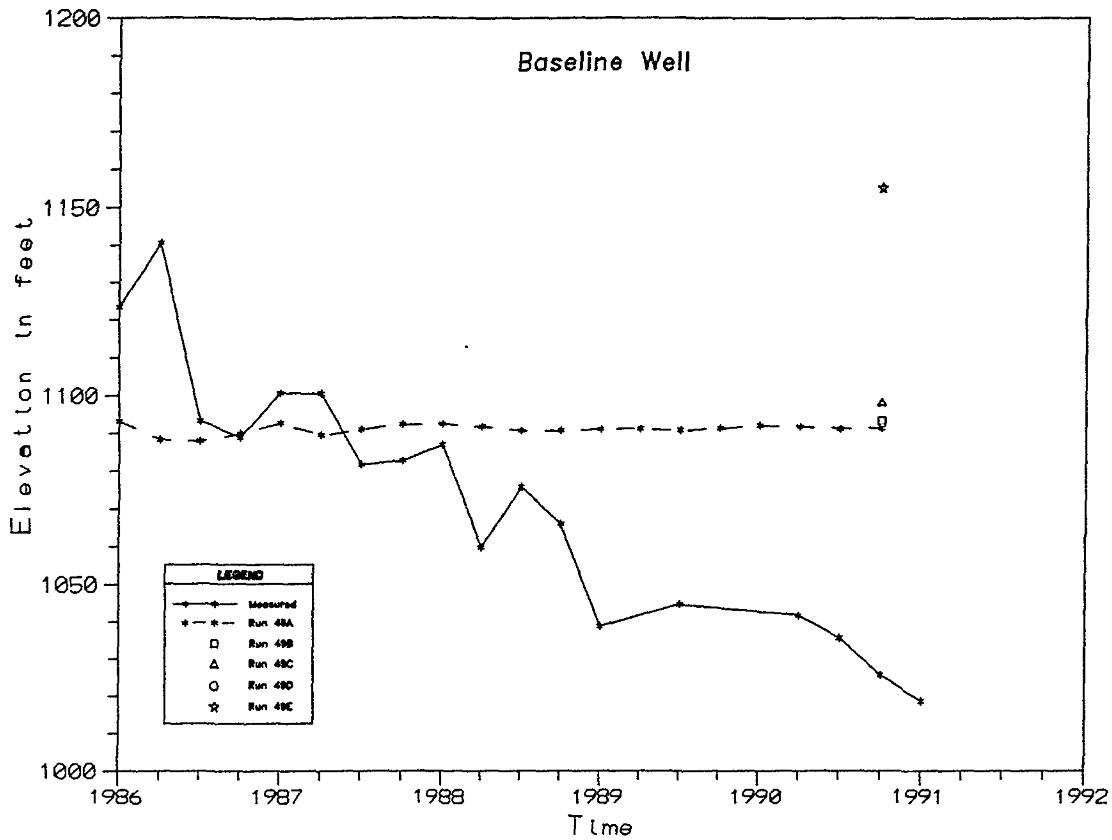
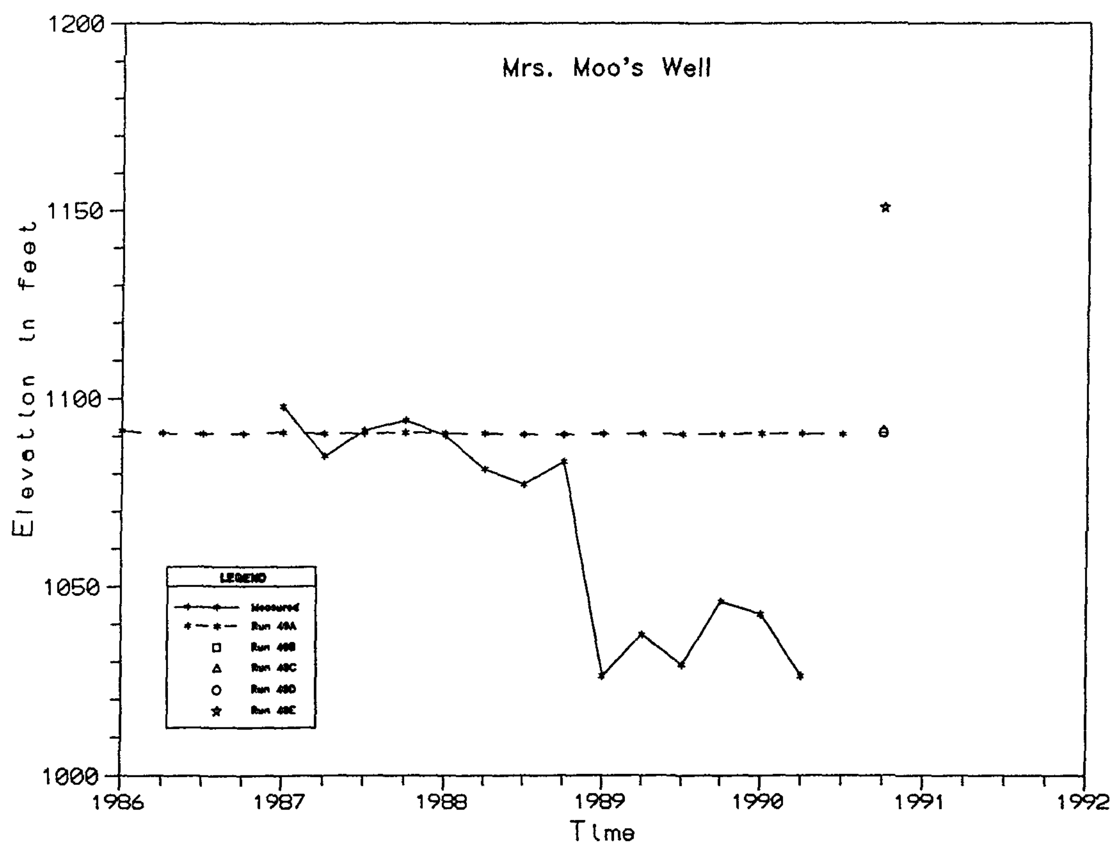
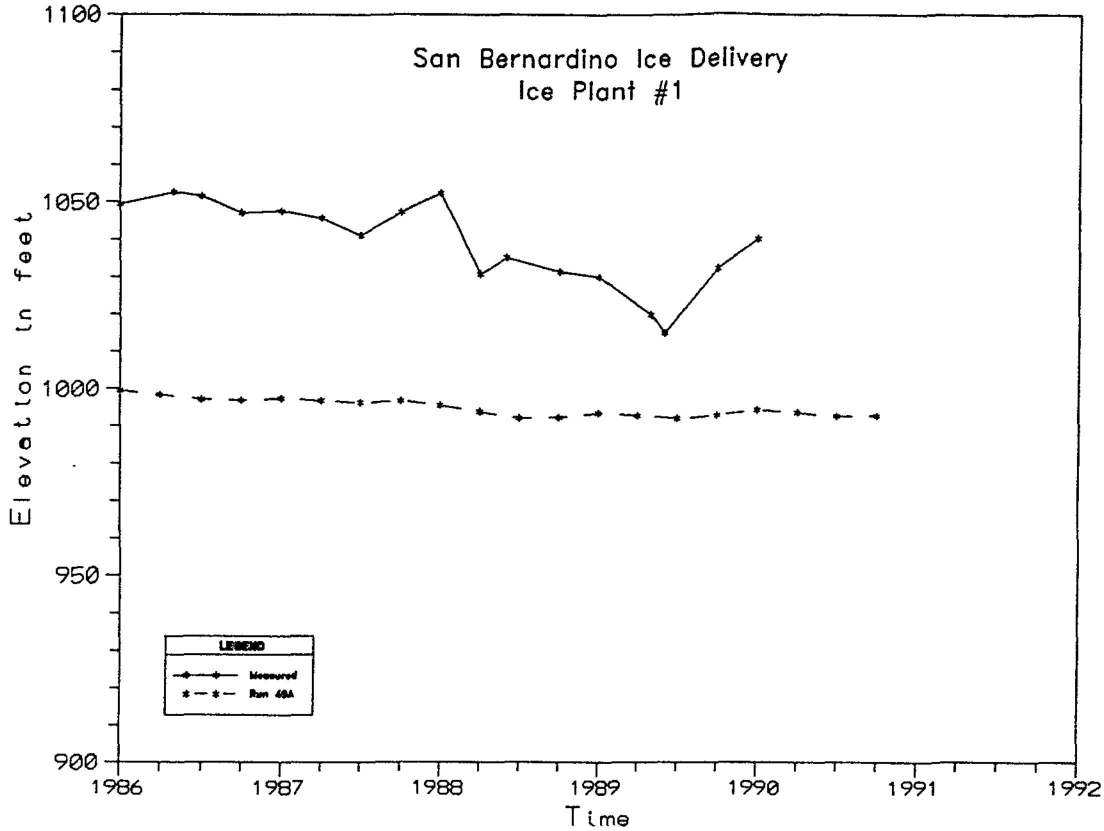
FIGURE 2

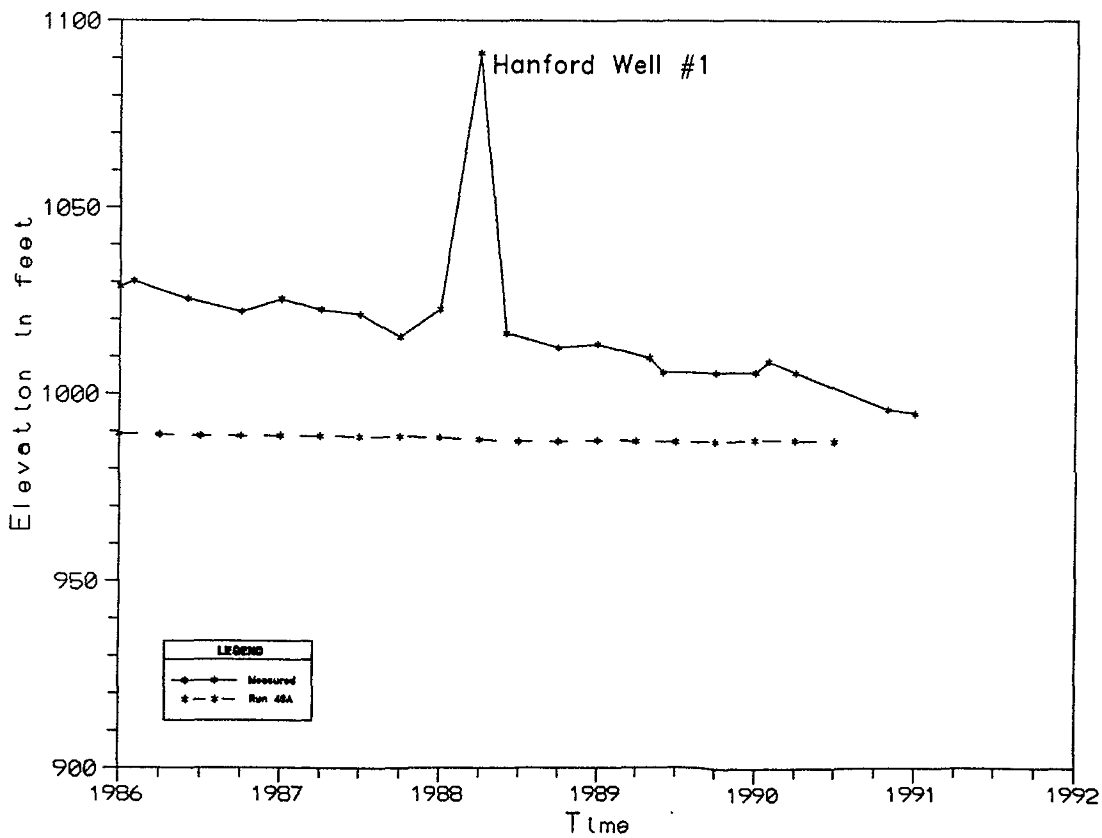
Hydrographs for 19th Street Wells #1 & #2



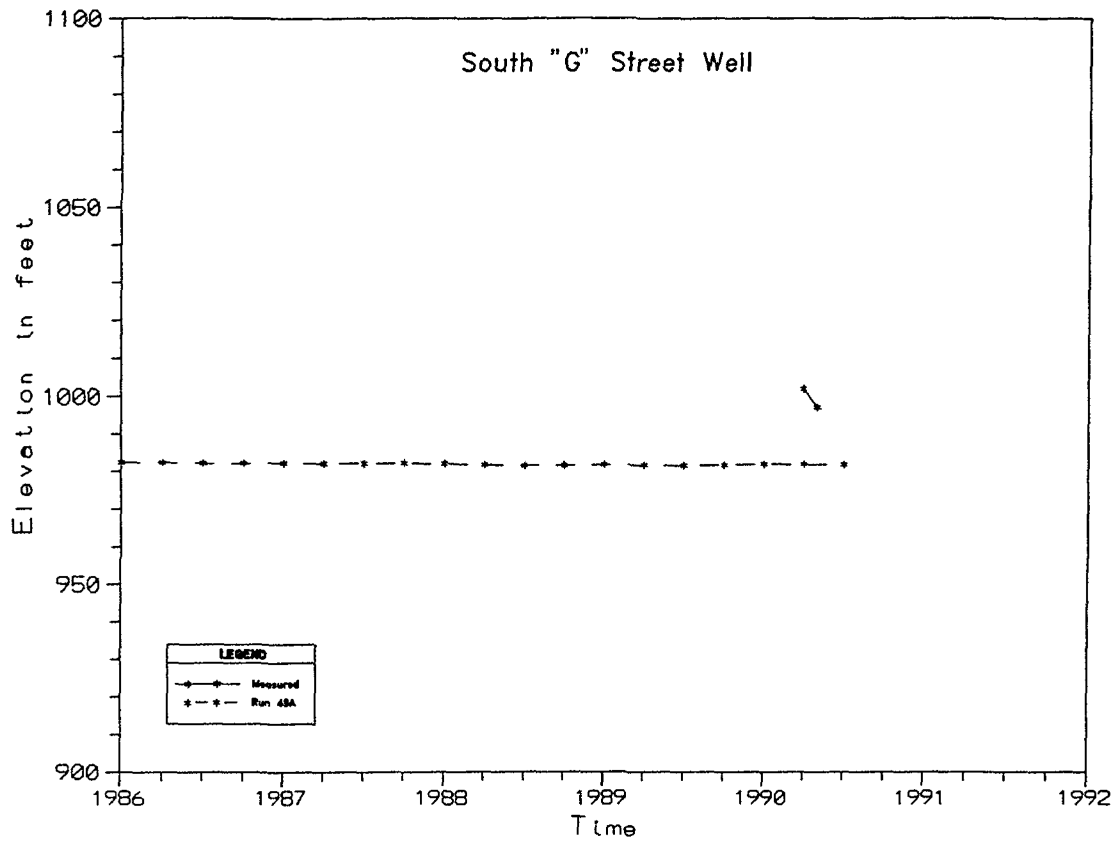


URS CONSULTANTS 2710 GATEWAY OAKS DR. SUITE 250 NORTH SACRAMENTO, CA 95834 (916) 929-2346	NEWMARK GROUNDWATER SUPERFUND SITE *MUSCOY OPERABLE UNIT* ARCS, EPA REGIONS IX & X WA NO. 54-10-9L26	**FIGURE 3** Hydrographs for Baseline & Mrs. Moo's Wells





URS CONSULTANTS 2710 GATEWAY OAKS DR. SUITE 250 NORTH SACRAMENTO, CA 95834 (916) 929-2346	NEWMARK GROUNDWATER SUPERFUND SITE MUSCOY OPERABLE UNIT ARCS, EPA REGIONS IX & X WA NO. 54-10-9LJ6	**FIGURE 4** Hydrographs for San Bernardino Ice Delivery, Ice Plant #1 & Hanford #1 Wells



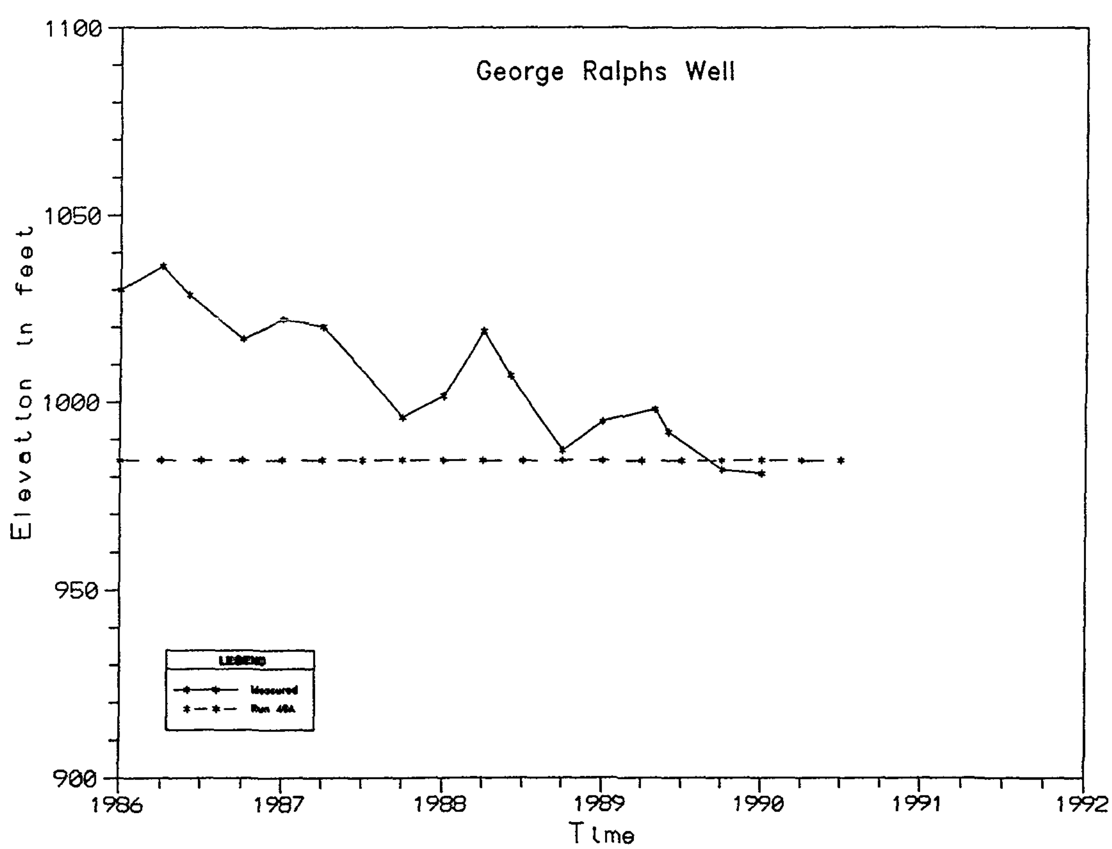


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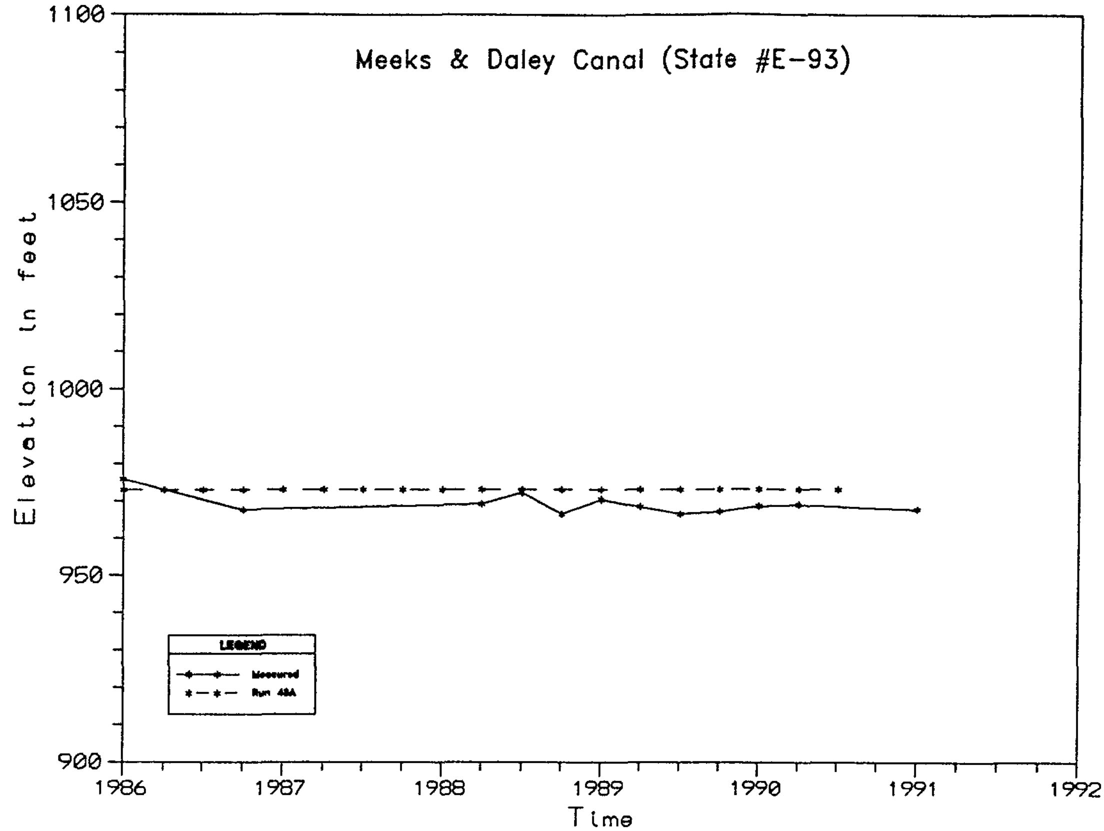
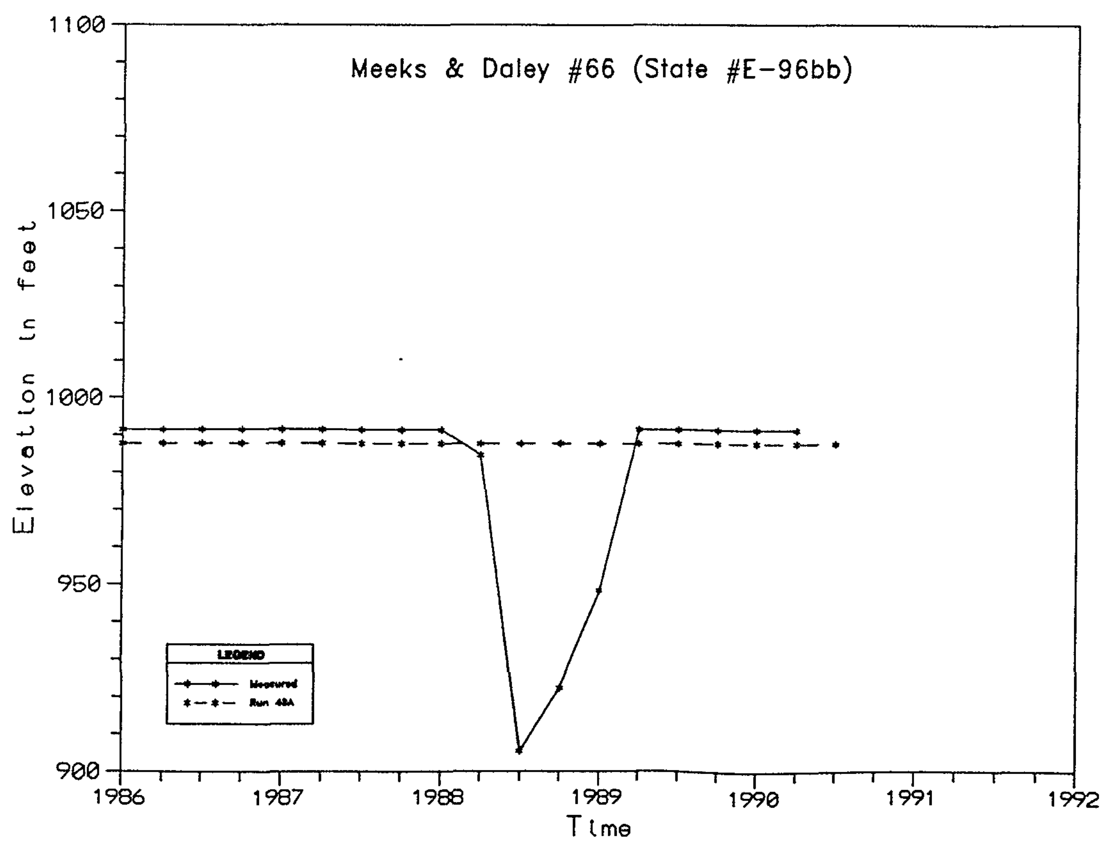
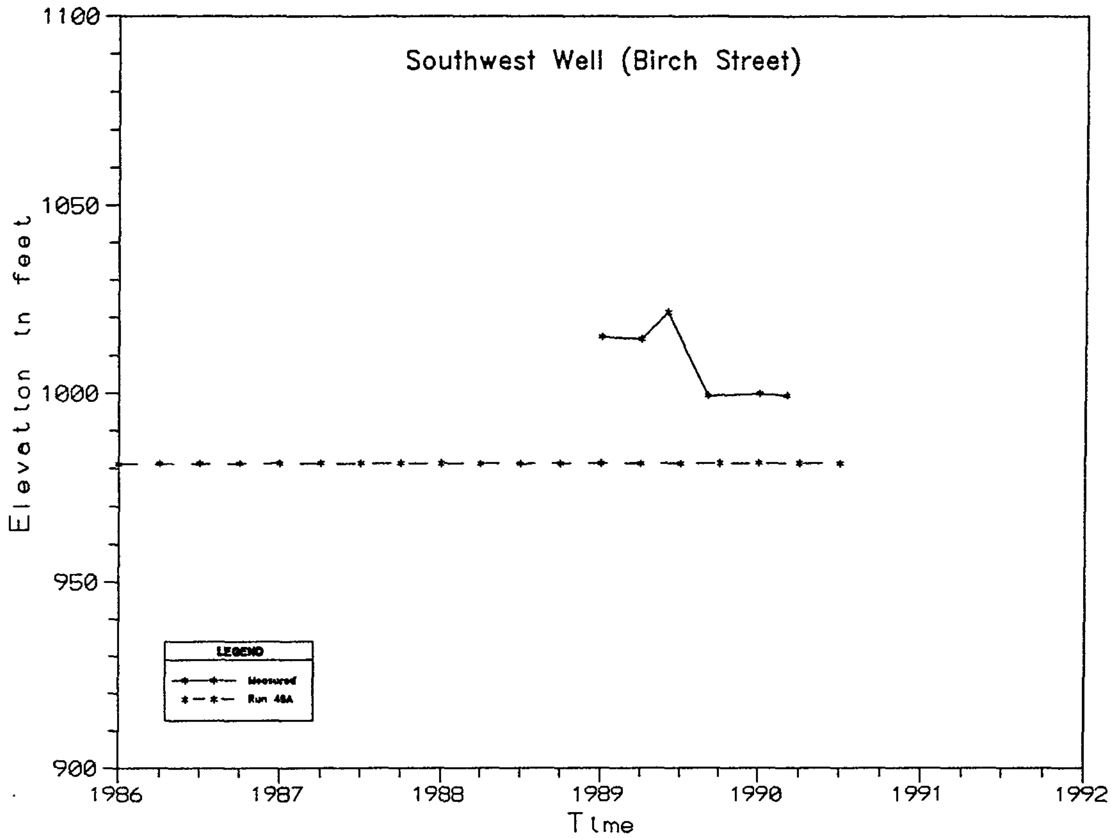
FIGURE 5

Hydrographs for South "G" Street & George Ralphs Wells





URS CONSULTANTS 2710 GATEWAY OAKS DR. SUITE 250 NORTH SACRAMENTO, CA 95834 (916) 929-2346	NEWMARK GROUNDWATER SUPERFUND SITE MUSCOY OPERABLE UNIT ARCS, EPA REGIONS IX & X WA NO. 54-10-9L26	**FIGURE 6** Hydrographs for Meeks & Daley Wells



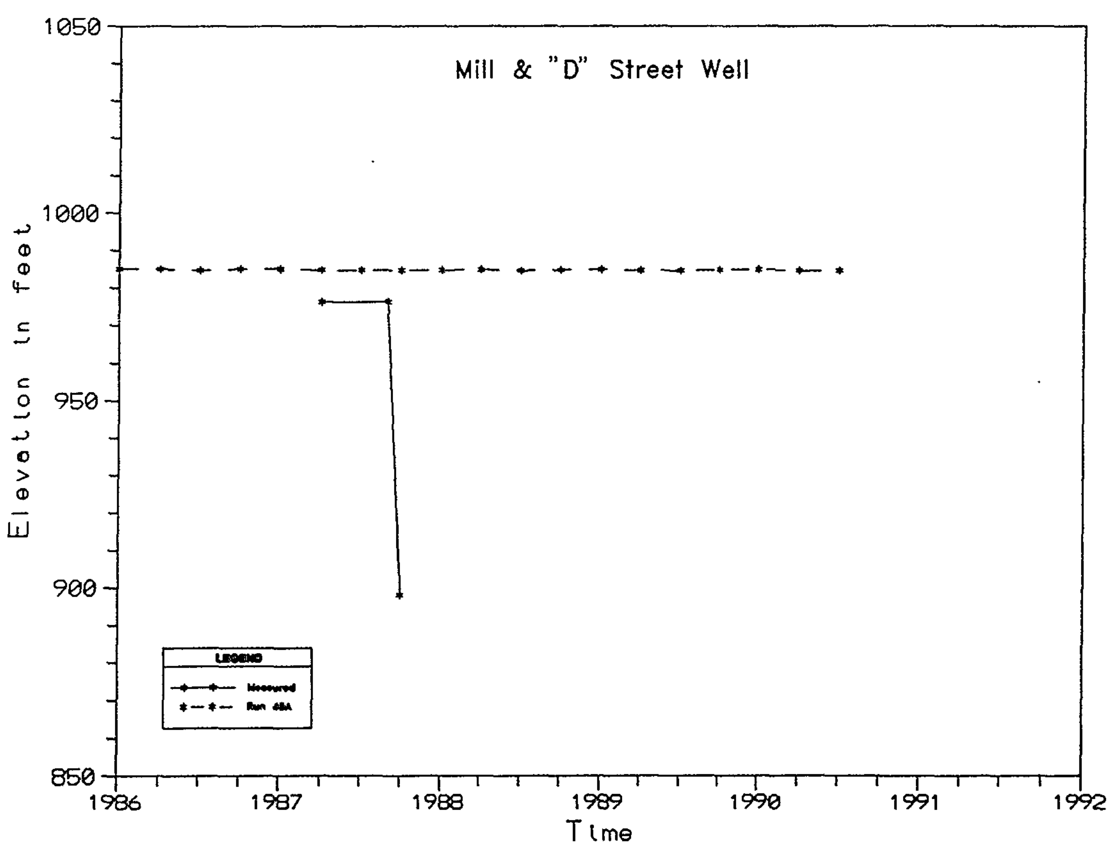


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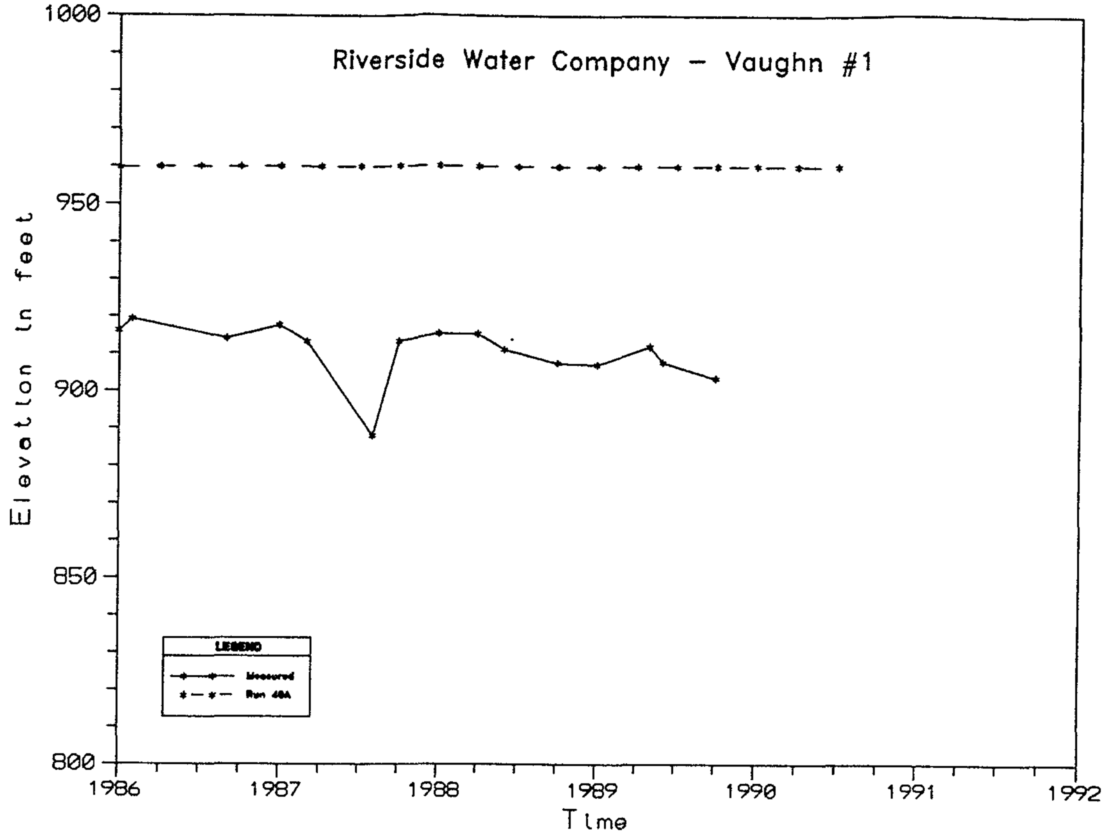
FIGURE 7

Hydrographs for Southwest (Birch Street) & Mill & "D" Street Wells



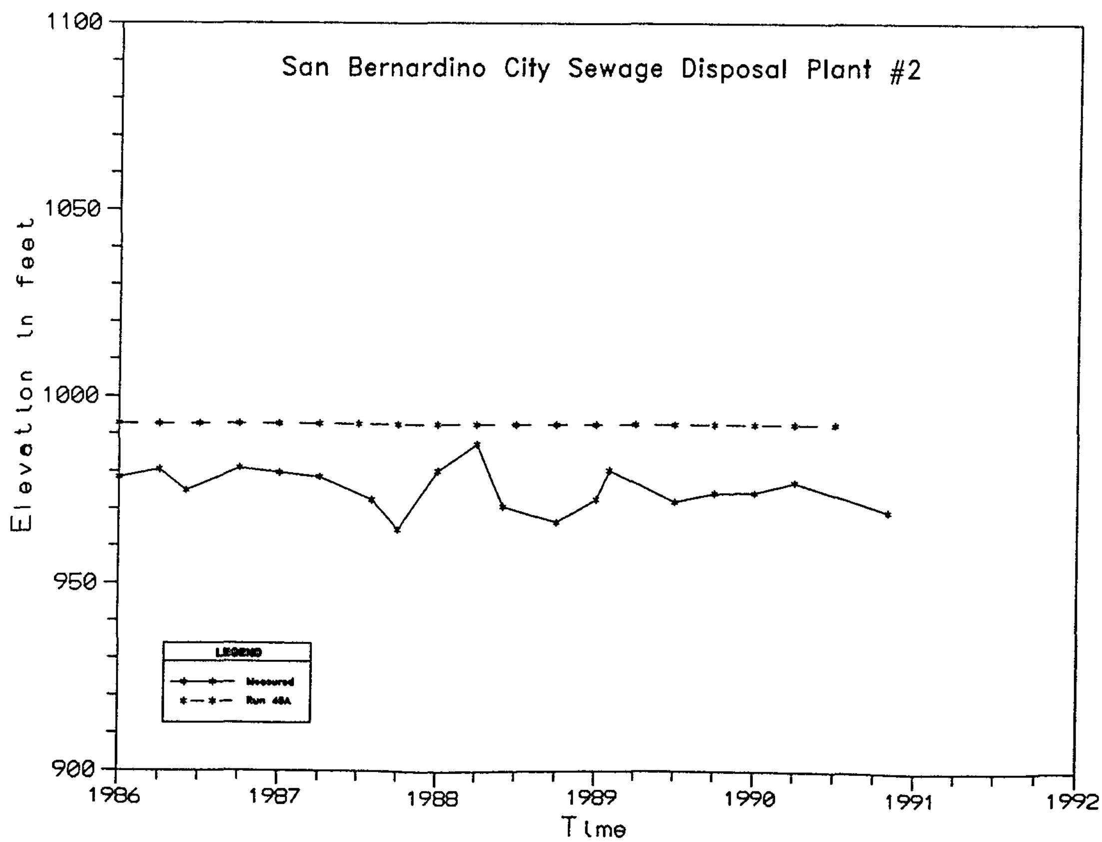


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FIGURE 8
Hydrographs for Riverside Water Company – Vaughn #1 & San Bernardino City Sewage Disposal Plant #2 Wells

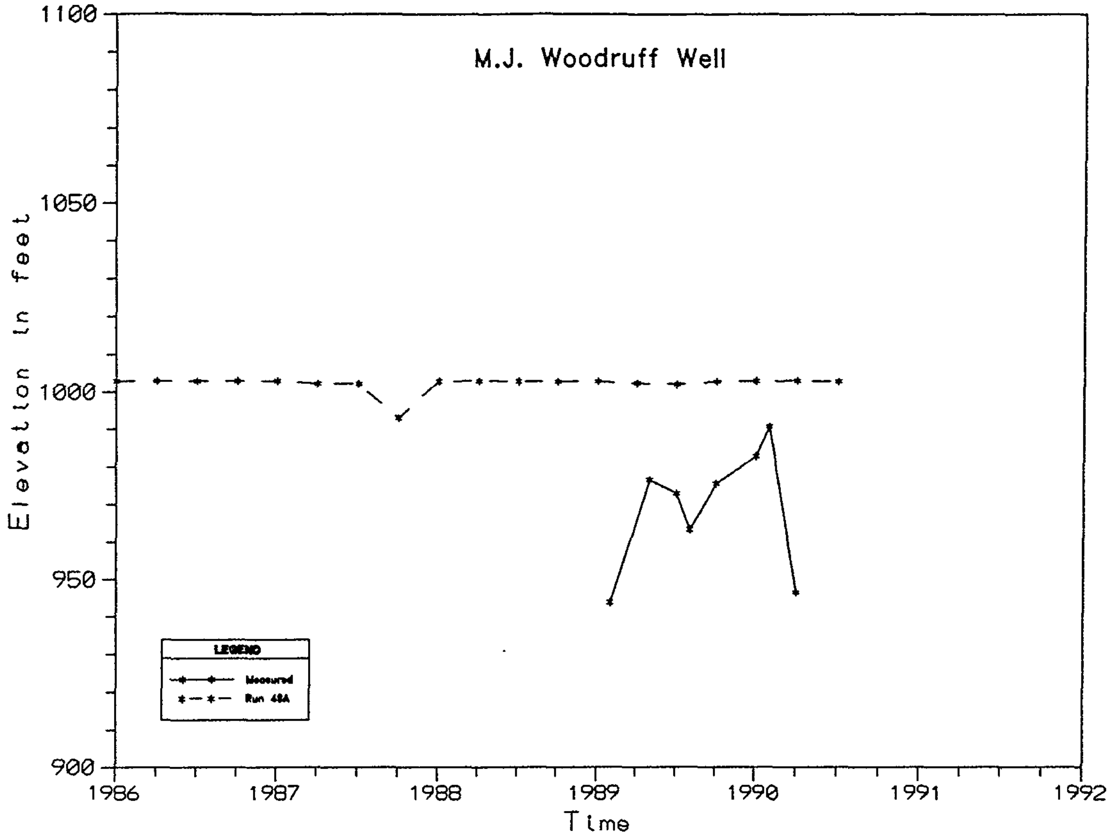

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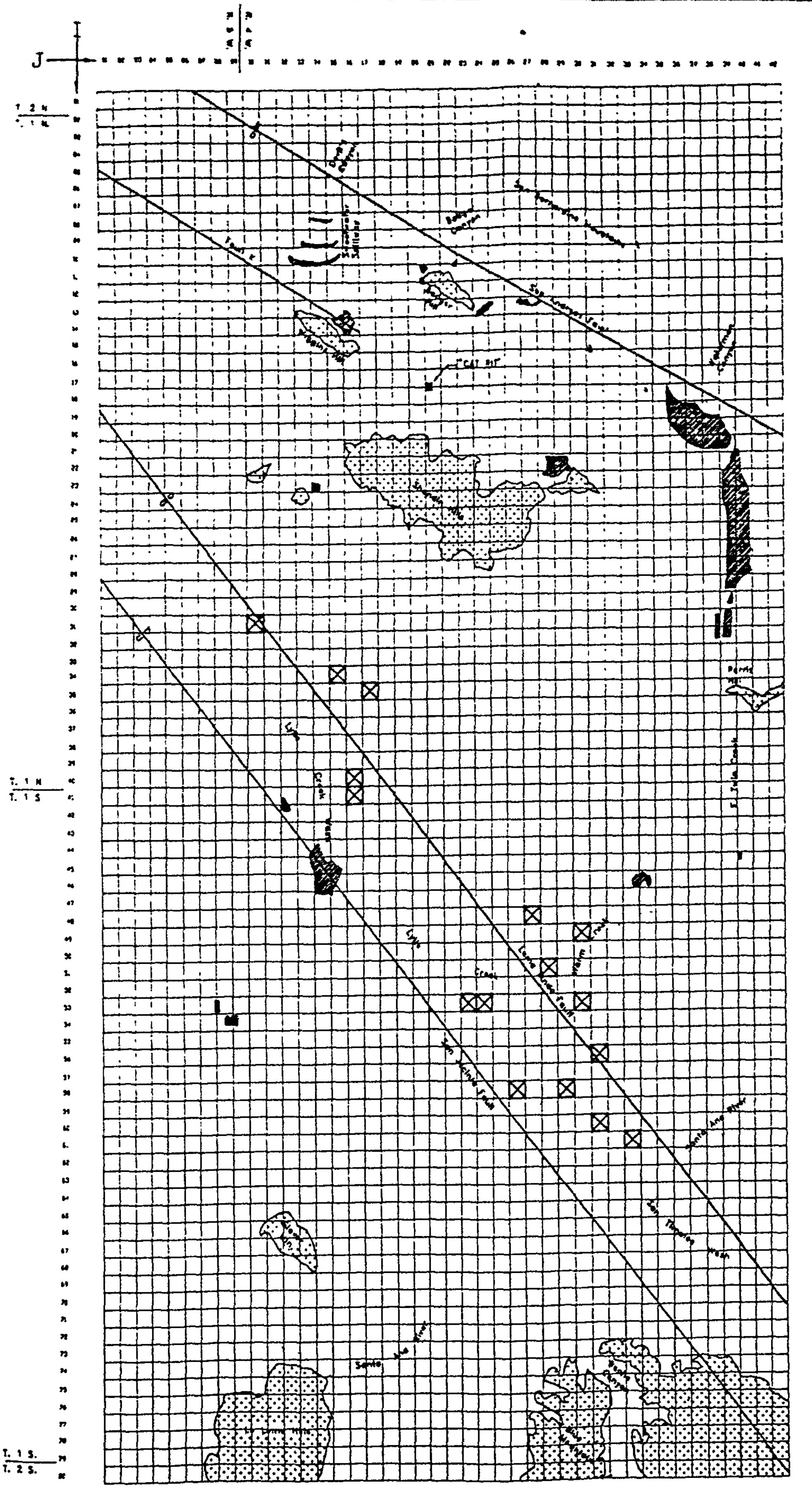
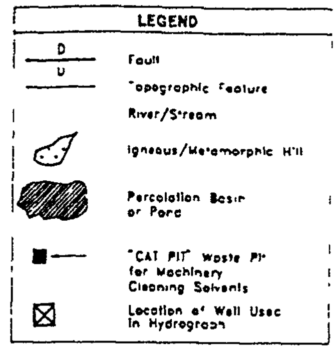
FIGURE 9

Hydrograph for M.J. Woodruff Well





WELL LOCATIONS

Well Name	I	J
19th Street #1	35	17
19th Street #2	35	17
Baseline Well	40	16
Hanford Well #1	49	30
Mallory Well #3	31	10
Meeks & Daley Canal	58	29
Meeks & Daley #66	56	31
Mill & "D" Street Well	53	30
Mrs Moo's Well	41	16
Mt. Vernon Water Company	34	15
George Ralphs Well	53	23
Riverside Water Co - Vaughn #1	58	26
San Bernardino Ice Plant #1	48	27
San Bernardino Sewage Plant #2	60	31
South "G" Street Well	51	28
Southwest Well (Birch Street)	53	24
M.J. Woodruff Well	61	33

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FIGURE 10
Location of Water-Supply and Monitoring Wells used for Hydrographs

2.3 EVALUATION OF DEFICIENCIES

The differences between the previous (Newmark) and the revised (Muscoy) versions of the transient-state model are key in defining why current calibration efforts have been difficult; differences have been both physical and conceptual in nature.

The presence of clay in the southern region of the Muscoy plume may affect the model solution: observational data show that the leakance values for the clay layer have no effect in terms of head difference between aquifers in the northern area of the Muscoy plume, but do create areas with 30-foot to 40-foot head differences between aquifers in the southern region. Although the overall head differences are not substantial, the buffering effect of the leakance between aquifers may be contributing to the model solution damping effect. Damping refers to the characteristic of the model to greatly smooth input variations in water levels (transient events). The most realistic situation may be represented by several non-contiguous clay lenses as opposed to the model simplification, that of a single clay layer.

The physical differences also include the number and spatial distribution of wells (or other sources, such as geophysical survey and analysis) for which there is data on depths to bedrock and water elevations. The level of confidence associated with the bedrock topography in the Muscoy OU is significantly lower than in the Newmark OU because of the lack of wells that penetrate to bedrock.

The model boundary conditions at the San Jacinto Fault may need refinement. This fault forms the southwestern boundary of the modeling area. The earlier model version (Newmark OU focused) did not focus on the western (Muscoy OU) side of the model. The localized boundary effects in the model near the San Jacinto Fault were not pertinent to the outcome of the Newmark modeling study. The current version of the model is focused near this Fault and treats the San Jacinto Fault as a no-flow boundary, based on literature research. This assumption may not be valid and probably inhibits satisfactory calibration.

Fault hydrodynamic deficiencies are evident when model water balance results are examined. Several calibration runs indicate discrepancies between predicted and observed heads that correspond to approximately 20 million gallons per day storage in the Muscoy plume. It is improbable that production wells of this magnitude escaped notice during data collection. It is more probable that leakage across this boundary could redistribute the excess water storage. In summary, model boundary conditions at the San Jacinto Fault are complex and should be examined in greater detail.

2.4 REVIEW OF VARIABLES AFFECTING MATHEMATICAL SOLUTION OF THE TRANSIENT-STATE MODEL

Major variables that affect the model include the following:

- Geometry and material properties (bedrock depth, alluvial thickness, hydraulic conductivity, specific yield).

- Stresses to the model (well pumpage, evapotranspiration, and recharge from flux along boundaries and rivers).

- Boundary effects of the no flow boundaries (particularly the San Jacinto and San Andreas Faults).

- Initial head values.

Table 1 illustrates the essential characteristics of these parameters. Question marks denote variables that need greater accuracy. Greater accuracy might be accomplished by performing sensitivity analyses during additional model runs.

Work performed to date indicates bedrock depth is a crucial element of model solution. Bedrock depth values and water level values define saturated alluvial thickness. Bedrock depth therefore regulates solution of the model in two ways -- it is the driving force (determined by the gradient) and the moderating/damping force (determined by the saturated thickness).

Alluvial thicknesses in the Newmark plume area vary from approximately 500 feet in the north (proximal) portion of the plume to 1000 feet in the south (distal) portion of the plume. In contrast, alluvial thicknesses in the Muscoy OU vary from approximately 350 feet to greater than 1,300 feet in the vicinity of the Perris Street well, illustrating the greater data variability in the Muscoy area.

General head boundary conditions are also very important in model solution. These provide groundwater flux into and out of specific model areas. Available observed flux data are non-existant in primary form. Rather, flux data are inferred from variables including hydraulic conductivity and groundwater elevation data measured across a boundary area. Confidence in these inferred data are primarily limited by the lack of groundwater wells along boundaries that could yield the conductivity and head values desired.

It has been observed that small variations of the general head boundary conditions have had limited effect on the model solution in the northwest areas of the model. The same variations had more profound effects in the southeast portions of the model.

Table 1

MUSCOY MODFLOW GROUNDWATER MODEL DATA RELATIONSHIPS

Issue	Sensitivity of model to input	Effort Required to Modify	Amount of Known Data	Confidence in Present Data	Model Overall Vulnerability
Bedrock depth and Alluvial thickness	High	High[1]	Low	Low	High
Hydraulic conductivity	Medium	Medium	Medium	Medium	Medium
Specific yield	Low	Low	Medium	High	Low
Well pumpage	Potentially High	Very High[1, 2]	Medium	Medium	Medium
Evapotranspiration	Very Low	Low	Medium	High	Medium
Flux from boundaries	High	High[1, 2]	Low	Medium	Medium
Recharge from rivers	Low	Medium	Low	Medium	Medium
Initial Heads	Low	Low	Medium	Medium	Low
Modify No flow boundaries to general head boundaries	?	Very High[1, 2]	Low	Low	Potentially High

1 High if difficult to acquire data.
2 Model input or testing represents a large task.

3.0 SUMMARY

3.1 WORK PERFORMED

Success in calibrating the refined model has been limited primarily due to insufficient data in the western, or Muscoy half, of the model. The observed and predicted heads are significantly different in this area; water mass distributions do not correlate either. The major deficiencies, potential causes or reasons for them, and recommended solutions are presented in Appendix B.

The model has been used to investigate suspected source areas utilizing imaginary particle placement analyses. Success has been qualified due to the limited resolution of the model in the area to the North and West of the Shandin Hills, the suspected source area(s). The current transient-state model may be used to qualitatively predict groundwater flow. However, because of insufficient agreement with observed data, it would not adequately quantitatively predict the flow.

The specific modifications made to the transient-state model during the particle placement analyses included the following revisions:

- Model active area. (Runs 43A,B, 45A,B)
- Initial head values. (Run 44A)
- Secondary storage factor. (Runs 45B, 49A,B,C,D,E)
- Specific yield values. (Run 49C)
- Hydraulic conductivity values. (Runs 49D,E)
- Bedrock elevation and alluvial thickness values. (Runs 45A,B)
- Head and conductivity values for the general head boundary condition grid cells. (Runs 49B,C,D,E)

Runs are profiled in Appendix A.

Revisions primarily address the problem areas and limitations persistent during the calibration of the transient-state model. These problems are listed below.

- Lack of proper correlation of measured and predicted water level data.
- Lack of proper correlation of measured and predicted gradients in specific areas.
- Lack of bedrock information.

- Lack of flux data across boundaries.
- Order of magnitude variations possible for hydraulic conductivity.

Specific field data necessary for further model refinement should focus on bedrock depth/alluvial thickness (structural data), pump testing to calculate hydraulic conductivities, and water level information. Bedrock topography and pumping data are the highest priorities.

3.2 RECOMMENDATIONS

This subsection identifies data necessary to enhance calibration of the model and perform predictive flow modeling in the Muscoy OU. Table 2 is a summary of general recommendations for flow model improvement and calibration. The table includes recommendations, rationale, and potential benefit from implementing the recommendations. Appendix B is a detailed compilation of model deficiencies and proposed solutions. Appendix B also includes general and specific recommendations for model improvement.

The discussion below expands on four areas that need further refinement.

Database. A well information database should be compiled. This would facilitate queries based on user specified criteria. Some of the data might be collected in pre-existing electronic format through the city of San Bernardino. It would provide an invaluable tool for referencing what data were and were not used in the model, as well as what the confidence level is in the raw data.

Bedrock Topography. A more detailed understanding of bedrock topography in the Muscoy OU is required if the model is to be more fully calibrated. Two major model variables are directly impacted by bedrock topography -- transmissivity and regional groundwater gradient.

San Jacinto Fault. A better understanding of the leakage across the San Jacinto Fault (the southwestern boundary of the active model) is imperative for proper distribution of water within the model. This fault may exhibit very low permeability, but is likely not an aquiclude as it is currently represented in the model. It should be noted that the San Jacinto Fault is the single largest feature in the entire model and even a small leakage across this barrier would significantly affect the water budget.

Pumpage Data. An effort should be made to reassess existing well pumpage and find additional pumpage data that could affect the model solution and overall water budget. The earlier version of the flow model was conceived primarily for the Newmark plume. Well pumpage data that did not affect the Newmark plume (but might significantly affect the Muscoy plume) may have been overlooked or not included. The observed data in the hydrograph of Meeks & Daley #66 well (Figure 6) appears to contain a drawdown "spike" of 100 feet and a corresponding recovery curve which spans the three months afterwards. This is not represented by the model output, either because of a general unresponsiveness, or because of imprecise or insufficient pumpage values.

Table 2

GENERAL RECOMMENDATIONS

Recommendations	Rationale	Benefit
Maintain and enhance the URS well information database	Need quicker access to data. Hardcopy files are not conducive to efficient data searches.	Provide tool to quickly reference available data and track what data are input into flow model.
Acquire better understanding of bedrock topography in Muscoy OU.	Very little field data available. Need more confident understanding since model is dependent on accurate bedrock topography.	Would directly improve accuracy of bedrock topography and indirectly increase accuracy of transmissivity and regional gradients.
Develop better understanding of hydraulic dynamics of San Jacinto Fault.	Current assumption in model that San Jacinto Fault is a no-flow boundary is probably incorrect.	Could improve water mass balance in model. Would make model more closely represent field parameters.
Reexamine existing well pumpage and acquire additional pumpage data.	Current pumpage in Muscoy OU may not be accurate since Newmark model did not focus on this area. Additional data may be available.	Could increase accuracy of model and improve water mass balances. Would make model more closely represent field parameters.
Perform a comprehensive sensitivity analysis of model input variables.	Sensitivity analysis not previously conducted for Muscoy OU. Current understanding of model parameter interaction in Muscoy OU could be improved.	Could greatly improve ability to enhance calibration of the model. Potentially could provide alternate way to substantiate model accuracy.

Sensitivity Analysis. A sensitivity analysis of model input variables including bedrock elevation, boundary effects, and hydraulic conductivity should be performed for the Muscoy OU. The current understanding of how sensitive the model is to changes in these variables needs development. A more thorough understanding of model sensitivities could enhance calibration and help reduce the number of calibration runs. Sensitivity analyses have also been used to substantiate model accuracy in certain situations. This could be useful if calibration proves problematic.

4.0 CONCLUSIONS

Based on the most recent model runs, the flow model appears to predict reasonable responses to pumping, given the current input data set and calibration state. An additional model run was conducted to simulate known pumping rates at the 9th and Perris Street production wells. Predicted head values were similar but less than the known values from the 1990 pumping tests. The pumping rates were obtained from a San Bernardino Valley Municipal Water District report titled *Baseline Feeder Wells, Ninth and Perris Street, Results of Drilling, Testing, and Recommended Pump Design* dated May 1990. If the pumping test results are assumed to represent accurate, long-term head drawdowns, then model capture predictions should be conservative. Uncertainty still exists, however, since the pumping test analysis used very short duration (days) data and projected drawdowns at one year were calculated on a linear basis. If the linear basis for the pumping test projections is not valid, then the flow model may be less conservative.

Preliminary model calibration is complete. The current input data set allows order of magnitude predictive responses to pumping. The model is sufficiently calibrated for use to predict pumping scenarios during the Feasibility Study; however, a greater level of certainty in the model is needed before it is applied to remedial design. The level of certainty may be increased by modifying the flow model as recommended herein.

Implementation of the proposed recommendations could represent a significant effort. A sensitivity analysis of model parameters such as bedrock elevation, boundary effects, and hydraulic conductivity should be conducted. The sensitivity analysis would require a substantial number of runs. Additionally, until there is better bedrock topographic definition (e.g., exploratory boring or geophysical studies) it is probably not efficient to further enhance model calibration.